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Dynamic Analysis of Car Suspension Using ADAMS/Car for Development of a Software Interface for Optimization

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Abstract

The design of a vehicle suspension, which is truly a multi-degree of freedom mechanism, is really challenging. This paper primarily focuses on Kinematics and Dynamic analysis of the system in ADAMS. A specific module of chassis platform is developed to analyze suspension ride comfort on adaptability to different vehicle with ADAMS/Car. The work intention is to make a parametric ADAMS model and then link it to a Knowledge Based Engineering application to facilitate designer to quickly carry out designing iterations in order to reduce development time. The Knowledge Based Engineering software is made using object oriented language called 'Object Definition Language' which is developed using VC++ software languages. The module not only carry through parametric modeling of front and rear suspension and other subsystems of chassis quickly and compactly, but also can carry on the analysis and optimization of various factors those have crucial impact on ride comfort. The module offers two test-bend, vehicle virtual simulation test stand and four-post test rig. Finally, the module is applied to analyze two kinds of cars which used chassis platform: front and rear frequency determination, pulse inspiration simulation and B-road simulation. The results show that the chassis platform being adopted by two kinds of cars meet the ride comfort requirements.

Keywords: chassis platform; suspension; simulation; ride comfort;

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1. Introduction

The chassis platform is currently major automobile manufacturer's technical strengths on world. They may use the chassis platform for the foundation, in view of the concrete vehicle type's segmentation market analysis, to make the local adjustment in chassis platform and even develop various vehicle types

Nomenclature

n_1	front part of vehicle body's natural frequency
n_2	rear part of vehicle body's natural frequency
c_1	front the suspension stiffness
c_2	rear the suspension stiffness
m_1	quality on the front suspension spring
m_2	quality on the rear suspension spring
$G_q(n)$	road space displacement power spectral density
$G_q(n_0)$	road roughness coefficient
n	spatial frequency
n_0	spatial reference frequency; $n_0 = 0.1\text{m}^{-1}$
w	frequency index, w=2
N	number of frequencies which is included in the pseudo-random signal
f_i	frequency of pseudo-random signal
x	vertical position of two-dimensional road
φ_i	phase angle which is generated by the random function, the range is 0~π
A_i	corresponding amplitude of the corresponding frequency
$f_{\min}$	lower frequency limit of a pseudo-random signal
$f_{\max}$	upper frequency limit of a pseudo-random signal

to satisfy different market demand with the existing platform, so that they can seize the market fast and win a larger profit. At the same time, through multi-types chassis platform development, you can grasp the key technology, form independent intellectual property rights of the core technology products, for automotive parts industry there have a very important strategic significance to upgrade and improve the competitiveness.

Automotive product development has risk such as high cost, long cycle, low success rate and high risk. By developing a design analysis platform for multi-types chassis platform suspension, you can carry on the virtual simulation design first, until its various indexes meet the requirements, and then turn to physical design, thus save a lot of automotive design steps, time and money. The suspension system must guarantee that the automobile has good ride comfort. So it is necessary to build a simulation model in order to analyze vehicle ride comfort. This paper is based on multi-body dynamics software ADAMS/Car and VC++ for the development and developed a set used for analysis ride comfort of multi-types suspension of chassis platform analysis specific module. This module can implement vehicle model and its subsystems of parameterized automatic modeling, and can analyze various factors which affect vehicle ride comfort, as well as carries on the post-processing to the simulation results data.

2. Chassis Platform of Suspension Ride Comfort Analysis Module

This system is based on ADAMS/Car and VC++ as a development platform. The system's main functions include: (1) The parameterization automatic modeling function of front and rear suspension systems, steering systems, front and rear anti-roll bar system, car body system, front and rear wheel system, which is used to create and modify subsystem in vehicle assembly. (2) Automated assembly function of vehicle model, used in related subsystems which assembles in the vehicle model. (3) Front and rear frequency automatic measurement function, used to measure and determine whether the vehicle front and rear frequency meet the ride comfort requirements. (4) Automatic simulation analysis function, for entering the national standard test condition data to conduct automatically simulation analysis. (5) Data post-processing function, used to recreate the working state of animation and extract simulation data according with car evaluation standards. (6) Optimized function, for modifying relevant parameters on the vehicle model to meet the ride comfort requirements. All functional modules transfer ADAMS/Car through VC++ to complete.

2.1. Parametric modelling function module for each subsystem

The functional module of establish front and rear suspension model. Transfer subsystem modelling menu through the VC++ interface, then choose suspension system model menu to select the front suspension type and drive mode, then the system will automatically transfer out the front suspension modelling interface of corresponding suspension type and drive mode. The model can complete through inputs the relevant parameters in the input dialog box of model interface. Here to adopt a chassis platform model (WX1 as code name) as an example carries on the explanation. WX1 front suspension is Macpherson suspension, drive way is front placed and front drive, when have selected of such conditions in the VC++ menu interface, system will assign out the model menu of front-wheel drive type Macpherson suspension according to the choice condition automatically.

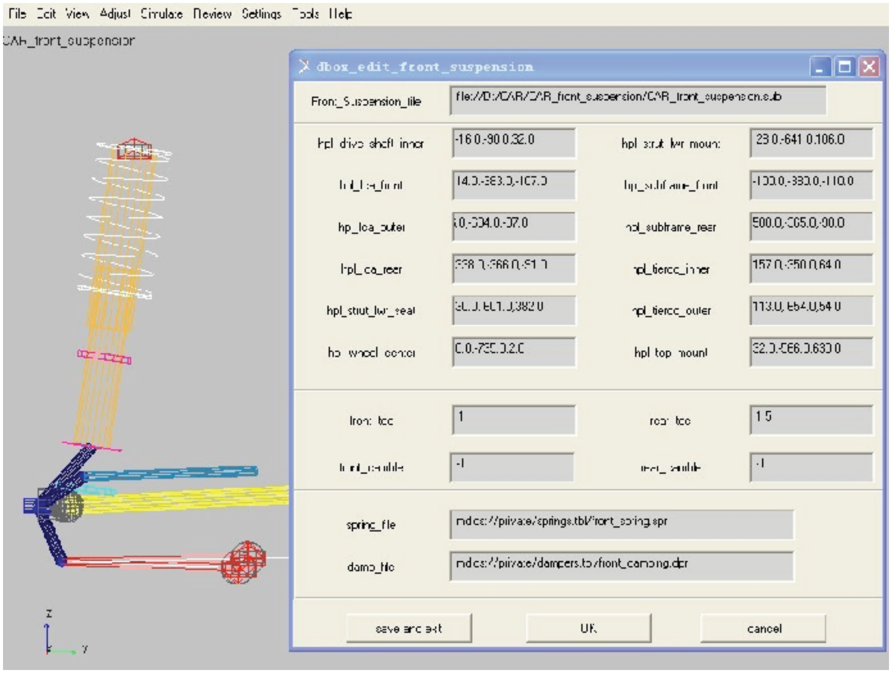

Fig.1 Input parameters established model of front suspension.

Then input the open path of the corresponding suspension system properties files in model menu, after that, input corresponding hard points of each suspension hinge in suspension system model interface, like spiral spring stiffness, shock absorber damping, toe angle, camber, and so on. And then click OK, the system will automatically create suspension model depending on the chosen properties file and input parameters. When model is completed, you can view the established model by ADAMS/Car interface. And then click Save and Exit, the system will automatically store the model of the front suspension in the designated location for to be called when the vehicle assembly and exit, shown in Fig.1. The steps of establishing rear suspension model are the same as that of the front suspension, just input interface parameters is slightly different.

The functional module of establish vehicle body model. In this paper, the establishment of the vehicle body has taken into account the impact of driver, passengers, luggage and other mass distribution to the ride comfort [1]. Establish a simplified seat-people model in the vehicle body and conduct a secondary development. When to model vehicle body, transfer the relative command through the VC++, and then enter the relevant parameters in the modelling interface, the vehicle body model can be completed.

The functional module of establish other subsystems model. The modelling way of steering system, engine system, front and rear antiroll bar system, front and rear wheel are similar to that of front suspension modelling, transfer related modelling interface through modelling menu of VC++ interface, and complete the system modelling by inputting relative parameters to modelling interface.

2.2. Vehicle modelling functional module

For vehicle modelling, the analysis system provides two kinds of test bench (MDI_SDI_TESTRIG, ARIDE_FOUR_ POST_ TESTRIG). When it come to virtual vehicle simulation analysis, the system will automatically step out vehicle assembly interface by transfer the vehicle assembly orders through VC++

and automatically call MDI_SDI_TESTRIG test-bench to assemble with each subsystem. When it comes to four-post test rig simulation analysis, the system will automatically choose ARIDE_FOUR_POST_TESTRIG test-bench to assembly with each subsystem. After completion of each subsystem choice, click OK to complete the vehicle assembly and finally click Save and exit, assembled vehicle model will be saved in the specified location, waiting for the next analysis.

The establishment of a chassis platform needs to be verified so that it can be applied to different models. In this paper, taking two types of vehicle WX1 and WX2 as an example which share chassis, by modifying the track, wheelbase, center of gravity's location, vehicle quality, tires and other parameters of chassis platform, then establish two different parameters of vehicle model, shown in Fig. 2.

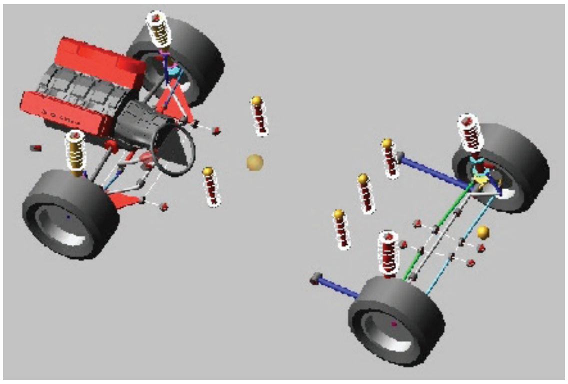

Fig.2 The simulation model of WX1 and WX2.

Table 1.Two vehicle main parameters contrast.

Main parameters	WX1	WX2
full mass (kg)	1607	1845
front axle load (kg)	829.5	849
rear axle load (kg)	777.8	996
track front (mm)	1470	1420
track rear (mm)	1470	1440
front suspension stiffness ($N \cdot mm^{-1}$)	24.7	24.7
rear suspension stiffness ($N \cdot mm^{-1}$)	15.56	15.56
height of center of mass (mm)	680	595
distance between centroid and front axle (mm)	1042	1132
distance between centroid and rear axle (mm)	1566	1563

2.3. Ride comfort simulation analysis function module

Referring to the requirements of national standard test condition, a ride comfort simulation function modules based on vehicle virtual simulation and ride comfort simulation function modules based on four-poster test rig is developed. This function module can achieve the following requirements: test the front and rear offset frequency; optimization of the amount of nodded in the braking and rise in the accelerating; optimization of antiroll bar stiffness; analysis and optimization of ride comfort simulation under the excitation of roof bump pulse and rectangular pulse; ride comfort simulation analysis and optimization on the class of B and C road. Thus, it can automate operating variety of conditions of the ride comfort simulation analysis by calling the relevant command through VC++ interface, and adjust the relevant parameters through the user input interface. There is a B-class road ride comfort simulation analysis and optimization interface. It can automatically perform simulation, view simulation animation, and modify spring stiffness and shock absorber damping by clicking the relevant button on the interface.

2.4. The results of data post-processing function module

For each simulation analysis module, there is a corresponding result data post-processing module, using this module, not only it can easily read a variety of data about displacement, velocity, acceleration and force of interaction between components from the simulation results, but also it can get further information on vehicle performance data, such as the each axial acceleration power spectrum of vehicle body and seats, as well as the national standard for evaluation indicator data of various types of vehicles. In this way, automotive designers can very easily and intuitively get the designed vehicle performance information, thus to improve their design efficiency. After the simulation completes, comes to the post-processing function modules. You can view the power spectral density curve of each axial acceleration of driver and co-driver seat by clicking the appropriate button.

3. Ride Comfort Simulation Analysis

3.1. Front and rear offset frequency determination

The natural frequency of vibration system which is formed by front-rear suspension and the quality on spring is one of the main parameters that affect vehicle ride comfort. The expression of front and rear part of vehicle body's natural frequency n_1 and n_2 is:

$$n_1 = \frac{\sqrt{c_1/m_1}}{2\pi} \quad n_2 = \frac{\sqrt{c_2/m_2}}{2\pi} \tag{1}$$

In the above calculation formula: c_1 and c_2 are front and rear the suspension stiffness; m_1 and m_2 are the quality on the front and rear suspension spring.

According to the natural frequency and damping ratio determination method on vehicle suspension systems in the literature 2, and the secondary development to ADAMS/Car, two testing systems which test front and rear offset frequency through the four-post of or virtual simulation are established.

There is the virtual test system which tests the front offset frequency. Having used this virtual simulation test system to test the front and rear offset frequency of the WX1 and WX2 respectively. And respectively measured the front and rear offset frequency of WX1 were 1.38Hz, 1.20Hz; WX2 were 1.4 Hz, 1.28 Hz. Based on the requirement of partial frequency in literature 3, we can see that the two types of models' front and rear offset frequency all meet the ride comfort requirements.

3.1. Pulse excitation simulation and analysis

According to the request of national standard GB5902-86 [4], the module has developed two kinds of pulse excitation (triangular pulse excitation and rectangular pulse excitation) as pulse inputs. In post-processing interface with the largest acceleration response (absolute value) from passenger seat as the evaluation standard, use the new draft called ISO2631 as evaluation method on the health as the basis for evaluation, The ride comfort evaluation index limits under the input of pulse in ISO2631 are: chair passed to the passenger of the maximum acceleration response more than 43.02 will be hazardous to health, lower than 31.44 will be no hazards to health, in this range between 31.44 to 43.02 has a certain degree of hazards to health [5]. Select triangular pulse simulation of simulation system to analyze. It can be obtained that the vertical acceleration at the maximum of the driver's seat when WX1, WX2 respectively pass through the triangular pulse road with different simulation speed, from it can been seen that the largest acceleration response passing to the passenger is less than 31.44, and below constant speed, the pulse there has no harm to human's health.

3.2. Random road of ride comfort analysis

3.2.1. B-class random road documents generation

The random road model in ADAMS/Car that has not conformed to national standard, according to the requirement of reference [6], first use the following formula to solve a road space displacement power spectral density:

$$G_q = (2\pi n_0)^2 G_q(n_0) \tag{2}$$

In the above calculation formula: $G_q(n)$ is road space displacement power spectral density; $G_q(n_0)$ is the road roughness coefficient; n is the spatial frequency; n_0 is the spatial reference frequency; $n_0 = 0.1m^{-1}$; w is the frequency index, w=2.

Next, use pseudo-Gaussian white noise power spectral density of road space velocity signal to obtain signal $G_q(n)$.

$$G_q(n) = G_q(n_0)\left(\frac{n}{n_0}\right)^{-\omega} \tag{3}$$

Finally, use the power spectrum inverse transformation function INVSPD in ADAMS/Car to generate random road data.

$$INVPSD = \sum_{i=1}^{N} A_i \cdot \sin(2\pi \cdot f_i \cdot x + \varphi_i) \tag{4}$$

$$f = f_{\min} + \frac{1}{N}(f_{\max} - f_{\min}) \tag{5}$$

In the above calculation formula: N is the number of frequencies which is included in the pseudo-random signal; f_i is the frequency of pseudo-random signal; x is the vertical position of two-dimensional road; φ_i is the phase angle which is generated by the random function, and the range is $0\sim\pi$; A_i is the corresponding amplitude of the corresponding frequency; $f_{\min}$ is the lower frequency limit of a pseudo-random signal; $f_{\max}$ is the upper frequency limit of a pseudo-random signal.

3.2.2. B-class road comfort simulation analysis

According to the vehicle ride comfort testing methods mentioned in the literature [7], the ride comfort simulation analysis system provides two kinds of arbitrary excitation simulation system, namely: virtual simulation of random road ride comfort analysis system, four-post test rig random excitation simulation analysis ride comfort system. Use virtual simulation of random road ride comfort analysis system to analyze ride comfort of WX1 and WX2. It was obtained that were three axis acceleration power spectrum of driver seat in WX2 and WX1. According to the literature [8] we can know that the most sensitive frequency range of driver seat vertical axis frequency weighting function standard is 4~12.5Hz, and the horizontal rang standard is 0.5~2Hz. Therefore, in the vertical direction of the acceleration power spectrum peak should steer clear of the sensitive range of 4~12.5Hz, and the horizontal peak should steer clear of the sensitive range of 0.5~2Hz. From the above three pictures we can see that three axis acceleration power spectrum peak of driver seat in WX2 and WX1 all avoid the scope of their sensitivity rang.

The weighting acceleration root-mean- square value can be calculated as:

$$a_w = \left[\int_{0.5}^{80} W^2(f) G_a(f) df \right]^{\frac{1}{2}} \tag{6}$$

W(f) is the frequency weighting function, the range is as follows:

- Horizontal vibration frequency weighting function can be expressed as:

$$W(f) = \begin{cases} 1.0 & 0.5 < f \le 2 \\ 2/f & 2 < f \le 80 \end{cases} \tag{7}$$

- Vertical vibration frequency weighting function can be written as:

$$W(f) = \begin{cases} 0.5 & 0.5 < f \le 2 \\ f/4 & 2 < f \le 4 \\ 1 & 4 < f \le 12.5 \\ 12.5/f & 12.5 < f \le 80 \end{cases} \tag{8}$$

- The total weighting acceleration RMS value can be calculated as:

$$a_{w0} = \left[(1.4 a_{xw})^2 + (1.4 a_{yw})^2 + a_{zw}^2 \right]^{\frac{1}{2}} \tag{9}$$

Lead the three axis acceleration power spectrum function data from the driver seat, and then use MATLAB software programming to find out the weighting acceleration RMS value as follows:

$$a_{wx1\_w0} = 0.286 \quad , \qquad a_{wx2\_w0} = 0.312 \tag{10}$$

According to the literature [4] in the evaluation criteria, WX1 and WX2 satisfy the ride comfort requirement.

4. CONCLUSIONS

By ADAMS/Car re-development, these subsystems' parametric modelling are completed: front and rear suspension subsystem, front and rear antiroll bar subsystem, steering subsystem, engine subsystem, front and rear wheel subsystem, vehicle body subsystem parameters of building mode. In ADAMS/Car platform, it built multi-types chassis platform suspension design and simulation system based on ride comfort, which offers two test stands: vehicle virtual simulation test stand and four-post test rig. Using this simulation analysis system, we can analyze various factors which affect the vehicle ride comfort. In addition, this system has highly commonality, and it can serve as a general ride comfort simulation analysis experiment platform, so it has very important value of engineering application.

By using this analysis module carried out testing front and rear offset frequency, pulse excitation simulation analysis and class of B road simulation analysis of vehicle (WX1 and WX2). The results showed that the two type of vehicle using the share chassis meet ride comfort requirements.

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